

LOCAL NORMAL GALAXIES

Carl E. Fichtel
NASA/Goddard Space Flight Center
Greenbelt, MD 20771

ABSTRACT

In the near future, high energy ($E > 20$ MeV) gamma ray astronomy offers the promise of a new means of examining the closest galaxies. Two and possibly three local galaxies, the Small and Large Magellanic Clouds and M31, should be visible to the high energy gamma ray telescope on the Gamma Ray Observatory, and the first two should be seen by GAMMA-1. With the assumptions of adequate cosmic ray production and reasonable magnetic field strengths, both of which should likely be satisfied, specific predictions of the gamma ray emission can be made separating the concepts of the galactic and universal nature of cosmic rays. A study of the synchrotron radiation from the Large Magellanic Cloud (LMC) suggests that the cosmic ray density is similar to that in the local region of our galaxy, but not uniform. It is hoped the measurements will be able to verify this independent of assumptions about the magnetic fields in the LMC.

I. INTRODUCTION

With this paper, the focus of this science symposium changes from our own galaxy and its contents to phenomena outside of it. The subject of this paper is normal galaxies, and specifically local normal galaxies since these are the only ones that would be expected to be detectable in the foreseeable future in the frequency range of high energy gamma rays. The local galaxies have been extensively studied at other wavelengths; some of the information from these observations, especially in the radio wavelength range are of considerable importance in the study to be described here. Gamma rays have not as yet been seen from any local normal galaxy beyond our own. The SAS-2 and COS-B gamma ray satellites which were launched in the early and mid 1970's were able to provide only upper limits to the gamma radiation from the closest galaxies. Calculations (Fichtel and Trombka, 1981, Houston et al., 1983, and Ozel and Berkhuijsen, 1987; Ozel and Fichtel, 1988), as well as those here, show that, on the basis of estimated density levels of the cosmic rays only upper limits would have been expected. Even with the next generation of high energy gamma-ray space instruments, only three appear to be detectable and, one just barely. The Large and Small Magellanic Clouds should be detectable at a level where several significant studies may be made.

There is an advantage to studying the other galaxies than our own in addition to the obvious merits of having more than a sample of one. Although they are further away and hence weaker and much less well resolved, there is not the complication of being buried inside in the middle of the plane as is the Sun. Hence, one does not have to attempt to understand variations over a large column throughout the plane

There are several facets associated with the scientific importance of studying galaxies in the frequency range of the high energy gamma rays. They include the fact that this is a quite direct means of measuring the

distribution of the nucleonic component of the cosmic rays, and hence the energy distribution of the cosmic rays since this component of the cosmic rays is by far the energy dominant one. Only the relevant matter distribution is needed to interpret the gamma ray measurements and this is reasonably well known. These data are free of the uncertainties associated with the synchrotron data, which also will be discussed here because they are quite important, but do require assumptions regarding the magnetic field and are related to the cosmic ray electron component which carries only about 1 percent of the total energy. The level and density distribution of the cosmic rays is needed to understand the dynamic balance existing in a galaxy and the scale of coupling of the cosmic rays to the matter. It will be seen that it also may be possible to improve the knowledge of the normalization parameter for molecular hydrogen or at least set a limit.

In this paper, the relevant information on local galaxies will be reviewed first, including the data related to atomic and molecular hydrogen and synchrotron radiation. Next the approach to calculating estimated gamma ray intensities will be outlined and the intensities to be expected from some local galaxies will be given. This section will be followed by a discussion of synchrotron radiation and its interpretation. Particular attention then will be given to the Large Magellanic Cloud. The subject matter to be described here will draw heavily on the paper of Özel and Fichtel (1988) and the work in progress of Fichtel, Özel, and Stone (1990), to be submitted for publication soon.

II. RELEVANT INFORMATION ON LOCAL GALAXIES

Whether one assumes the cosmic ray density in other normal galaxies is similar to our own or correlated with the matter, straightforward calculations of the type to be described in the next section suggest that only three are likely to be seen or close to being detectable by the next generation of high energy gamma ray telescopes. These are the Andromeda Galaxy, M31, and the Large and Small Magellanic Clouds. M31 is much further away, but is also larger. M31 would appear to be an especially attractive object for study because its structure and size are similar to our own. The Large Magellanic Cloud is only about 7 kpc in diameter and has much less mass than our own. The Small Magellanic Cloud has even less mass, but as will be discussed below, it has a possible bright region from the consideration of potential gamma ray emission. This paper, therefore, will be restricted to these three galaxies.

The three galaxies just mentioned will be discussed individually in regard to their hydrogen column densities. The angles between the normal to the plane of each galaxy and the line of sight are: 74° to 77° for M31, 30° to 33° for the LMC, and 60° to 73° for the SMC (Berkhuijsen, 1977; Ichikawa et al., 1985; de Vaucouleurs and Freeman, 1973; Luiseau et al., 1987).

The matter of interest for the discussion here is that with which cosmic rays interact to produce gamma rays. The basic observations needed are, therefore, those giving information on the diffuse atomic and molecular hydrogen. For atomic hydrogen, the interpretation, of the 21 cm data is, of course, straightforward, but, for molecular hydrogen, the CO measurements are not. The ratio N_{H_2}/W_{CO} , called X_G , is determined in a number of ways, including the gamma ray measurements in our own galaxy, and for our galaxy has

recently been estimated to be $2.8 \times 10^{20} \text{ cm}^{-2} \text{ K km s}^{-1}$ (Bloemen et al., 1984), although values in the range from $(1 \text{ to } 3) \times 10^{20} \text{ cm}^{-2} \text{ K km s}^{-1}$ have been proposed. This range of values is not, however, universally true, as will be noted later.

For the atomic hydrogen column density of the Andromeda Galaxy (M31), the results of Davies and Gottesman (1970) are used. The galaxy has an oblong shape with two principal gas density maxima. The southern parts of M31 have been studied in enough detail to indicate that the CO distribution is similar on a coarse scale to that of the HI gas. The molecular hydrogen appears to form in cloudlike structures similar in size and shape to the galactic ones. Available overall CO studies of M31 indicate that the total molecular hydrogen mass is about an order of magnitude less than that of the atomic hydrogen (Stark, 1979) and, therefore, is of much less importance for the production of gamma rays than in our galaxy.

For the atomic hydrogen column density, the 21 cm map given by Mathewson and Ford (1984) for the SMC and LMC is used. Their diagram differs in its HI contours from those of Rohlfs et al. (1984) by about a factor of two, but agrees well with the estimated total gas content of the SMC and LMC. The diffuse matter content of the Magellanic Clouds is known to differ from that of our galaxy in significant respects (Elmergreen et al., 1980). It is estimated that these smaller galaxies still contain 10 percent to 30 percent of their total mass in diffuse form, compared to a few percent for our galaxy and M31. The large size of the clouds and the weak emission require long integration times at a large number of positions for a full CO study. Cohen et al. (1988) have just recently completed a full survey of the central $6^\circ \times 6^\circ$ of the LMC with an angular resolution of $8''.8$ for the 1+0 line at 2.6 mm of CO. The emission is dominated by an extremely large complex of molecular clouds extending south from 30 Doradus in the general region of the maximum 21 cm emission. Cohen et al. found that the correlation of CO luminosity with linewidth is similar to that for Galactic clouds, but, for a given linewidth, the LMC clouds are a factor 6 fainter in CO, comparable to the factor of 4 lower metallicity in the LMC. Assuming $N_{\text{H}_2}/W_{\text{CO}}$ is 6 times larger in the LMC than in the Galaxy, or about $1.7 \times 10^{21} \text{ cm}^{-2} \text{ K km s}^{-1}$, the total molecular mass of the LMC is $1.5 \times 10^8 M_\odot$, and the ratio of molecular to atomic mass is about 0.4 for the region of the CO survey.

For the SMC, the atomic hydrogen content is reasonably well known also, and the map of Mathewson and Ford (1984) and that of Loiseau (1984) were used, as noted. In the SMC, the CO emission is even significantly weaker than the LMC. Primarily for this reason, a full coverage has not yet been achieved, with only selected points having been examined (Israel, 1984). On the basis of the low level of the emission, and also the dust density being observed to be smaller, it is generally assumed that the molecular content of the SMC is relatively small, with the ratio of molecular to atomic hydrogen by mass being no more than about 0.1 (Rubio et al., 1984). The total mass of the gas is then estimated to be $4.8 \times 10^8 M_\odot$. It should be noted that, whereas the observed atomic hydrogen column density is larger at its maximum for the SMC than the LMC in a limited region, the angle of the line of sight to the normal to the galaxy is larger for the SMC. The column density perpendicular to the plane of the SMC galaxy is estimated to be a factor of 2 1/2 or 3 smaller than the observed column density because of the large secant of the angle. The column densities perpendicular to the plane are then on the average smaller

for the SMC than the LMC. This feature is important in the discussion of the expected cosmic ray density to come later.

Synchrotron radiation also is detectable from local galaxies. Its interpretation is somewhat complex and involves some assumptions. Therefore, the calculation of expected high energy gamma radiation based on the matter distribution will be discussed first in the following section, with a description of the synchrotron radiation coming in the subsequent section to that.

III. CALCULATION OF ESTIMATED GAMMA RAY INTENSITIES BASED ON THE MATTER DISTRIBUTIONS

As cosmic rays, which consist of electrons, protons, and other bare nuclei, traverse space, they interact with the diffuse matter and photons to create gamma rays. They also interact with the magnetic fields, but for interstellar space this interaction is negligible for the production of gamma rays compared to the other two. The cosmic ray nucleon interactions with interstellar matter give rise to gamma rays primarily through the production of neutral pions, with other channels producing lesser numbers of gamma rays. The resulting gamma ray spectrum has a maximum at about 70 MeV and is approximately symmetric on a logarithmic energy scale. Cosmic ray electron interactions with interstellar matter lead to a monotonically decreasing spectrum. For the relative numbers of electrons and nuclei that exist in our galaxy, the combined spectrum is one which decreases with energy, but has a bulge in the region of the neutral pion peak. Electrons also interact with the interstellar photons, optical, infrared, and blackbody, to produce gamma rays through the Compton process. The Compton gamma radiation thus produced is also a monotonically decreasing function with energy, but, for the case of our galaxy, is much less intense than the bremsstrahlung radiation. A general discussion of these processes together with intensity estimates and references to the original papers is given by Fichtel and Trombka (1981). The principal justification for this explanation of the galactic diffuse radiation is that the resulting intensity distribution and energy spectrum for the diffuse gamma radiation in our galaxy match the observations well. See, for example, figures 5-5 and 5-6 in Fichtel and Trombka.

For the calculations performed here it was assumed that the approach just described is valid and that the correction for elements heavier than hydrogen is the same in the other galaxies as it is in our own. Therefore, as in the calculation in our own galaxy, an estimate of the hydrogen density is made and then multiplied by the appropriate factor. The source functions used are those in the work described above slightly modified to take into account refinements made in recent work, particularly in the nuclei-nuclei interaction part (Stephens and Badhwar, 1981, Morris, 1984, Dermer, 1986, Stecker, 1988). The source function used for the number of gamma rays procured for energies above 100 MeV was $2.0 \times 10^{-25} n_H r_C$ gamma rays $\text{cm}^{-3} \text{s}^{-1}$, where n_H is the number of hydrogen nuclei, atomic and molecular, cm^{-3} , and r_C is the ratio of the cosmic ray density to that in the vicinity of the Earth.

In considering the galaxies closest to our own, the interstellar hydrogen can be estimated from the measurements of the 21 cm line, and, as in the case of our galaxy, the molecular hydrogen can be estimated from the CO radio data and other considerations, as will be discussed for each individual case

below. The cosmic ray spectrum and composition in the other galaxies is, of course, not known. The best initial assumption appears to be that the processes which produce the cosmic rays in our galaxy are the same elsewhere, and, unless the pathlength and lifetime are dramatically different in the other galaxy, the spectrum should be similar. When gamma ray results exist, this assumption may be checked by comparing the observed spectral shape to the predicted one. Since the observable photon density in the nearby galaxies is similar to our own, and the blackbody radiation is presumably the same, the Compton contribution to the gamma radiation should be relatively small.

The density distribution of the cosmic rays in the galaxy is, in fact, what it is hoped that the gamma ray measurements will reveal. However, for the purpose of the work here, certain hypotheses will be made so that the predicted gamma ray intensity can be calculated. These results will serve two purposes. One is to provide an indication of the level of the gamma radiation

that might be expected, and the other is to provide a basis for testing the theoretical assumptions.

The simplest assumption is that the cosmic rays are uniform throughout the Galaxy; however, this is likely to be true only if the cosmic rays are universal rather than galactic. The greatest theoretical problem with the cosmic rays being universal is the large amount of energy required. It is too large to be supplied by galactic leakage, unless one assumes the average galaxy is quite different than our own. The cosmic rays would, therefore, have to be primordial. There are also other concerns, such as the energy spectrum. Further, most authors (Bignami and Fichtel, 1974; Paul et al., 1974; Schlickeiser and Thielheim, 1974; Bignami et al., 1975; Fichtel et al., 1975; Stecker et al., 1975; Puget et al., 1976; Paul et al., 1976; Hartman et al., 1979; Bhat et al., 1985; Bloemen et al., 1986; Strong et al., 1987) who have examined the question for our own galaxy conclude that the cosmic ray density is not uniform there. Although the various authors differ on details, they generally conclude that the cosmic ray density appears, at least on a course scale, to be enhanced where the matter density is greater. However, the limited existing data does not permit an absolute statement on this matter at present.

There are fundamental theoretical considerations also which lead to the conclusion that the cosmic ray density is correlated with the matter density, at least on the scale of arms and large clouds (Bignami and Fichtel, 1974). Briefly, under the presently generally accepted assumption that the cosmic rays and magnetic fields are primarily galactic and not universal, these fields and cosmic rays can only be constrained to the galactic disk by the gravitational attraction of the matter (Biermann and Davis, 1960; Parker, 1966, 1969, and 1977). Together the total expansive pressure of these three effects is estimated to be approximately equal to the maximum that the gravitational attraction can hold in equilibrium. Assuming the solar system is not at an unusual position in the galaxy, these features suggest that the cosmic ray density throughout the galaxy may generally be as large as could be contained under near equilibrium condition.

Perpendicular to the plane of the galaxy, since the scale height for the matter is small compared to that of the cosmic rays, the cosmic ray density may be taken as constant, i.e., independent of the distance perpendicular to

the plane, for the region relevant for the majority of the cosmic ray matter interactions.

Since the other galaxies being considered are being observed from the outside at other than a very small angle with respect to the plane, there is not the need to be concerned about variations of the cosmic ray density along the line of sight because the variations are believed to be on the scale of arms, or at least very large clouds. Then, the cosmic ray density may be removed from the integral and simply multiplied by the column density. Hence, for any direction the gamma ray flux above 100 MeV will be given by the expression:

$$j_{\gamma} = 2.0 \times 10^{25} \times \frac{1}{4\pi} (\int n_H dl + \int n_M dl) r_C \quad (1)$$

photons ($E > 100$ MeV) $\text{cm}^{-2} \text{s}^{-1}$

Here, r_C is the ratio of the cosmic ray density to that in the local region of our galaxy. There is a correction in the form of an addition for the Compton radiation, but it is almost certainly less than 10 percent for directions which are not within a small angle of the plane of a galaxy.

For the constant cosmic ray density case, $r_C = 1$. If the cosmic ray density is related to the matter on a coarse scale, then

$$r_C = \frac{(\int n_H dl + \int n_M dl)}{N_1 \times 10^{20} \cos(i)}, \quad (2)$$

where the average is taken over the region in question as long as its dimensions are of the order of a kiloparsecs or greater. N_1 will be taken as 8 corresponding to an average hydrogen nucleus density of just over one for the local arm of our galaxy in the plane and the local scale height.

The Magellanic clouds are about 60 kpc away and hence 1° corresponds to about 1 kpc. Both have dimensions somewhat larger than an arm segment in our galaxy. If the cosmic rays are local to the galaxy, and there have been enough sources to fill them to their energy containment limit, the cosmic ray density might be larger in the central region of the LMC than in the local region of our galaxy due to the larger average column density. A gradient in r_C would be expected. For the Small Magellanic Cloud, when the column density is corrected for the large inclination angle, it is smaller than for the LMC, r_C would be smaller, or perhaps about one or less.

M31 is much further away; 1° in its case corresponds to about 12 kpc. The discernible structure seems limited. The column densities are rather lower, and the cosmic ray density over the region would, therefore, under similar assumptions, be similar to the local cosmic ray density, possibly enhanced a bit near the two highest density regions, but lower on the edges. Hence, no significant cosmic ray enhancement averaged over a square degree is expected; over most of the remaining region, it would be less.

The expected intensities integrated over the whole galaxy are shown in Figure 1 for the case of $r_C = 1.0$. According to the discussion above, all of the r_C values might be expected to be near one. Gradients would be expected.

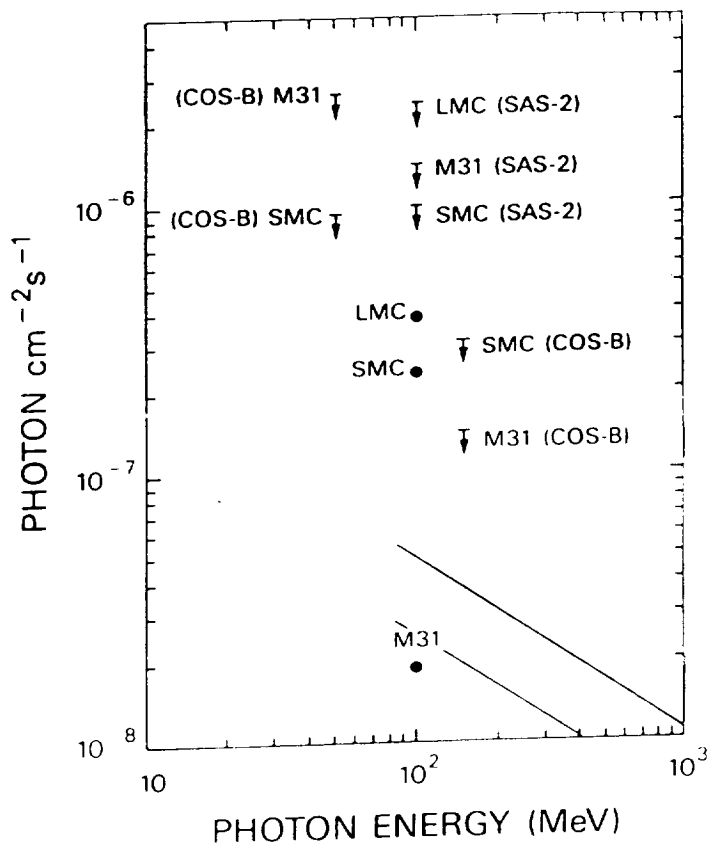


Fig. 1--Existing upper limits to the integral flux of gamma rays from the SMC, LMC, and M31 for the energy shown together with the fluxes calculated by Ozel and Fichtel (1988) shown as closed circles for the case where the average cosmic ray density is the same as in the local region of our galaxy. The SAS-2 limits are those of Fichtel et al. (1975), and the COS-B limits are those of Pollock et al. (1981). Also shown is the estimated GRO EGRET sensitivity limit for 2- and 4-week exposures; the GAMMA-1 limit is expected to be about a factor three higher. The exact sensitivity level depends also on the angle of the source with respect to the telescope axis as well as other factors.

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IV. SYNCHROTRON RADIATION

If the electrons have a spectrum of the form

$$N(E)dE = KE^{-\gamma}dE \quad (3)$$

where $N(E)$ is the number of electrons $\text{ergs}^{-1} \text{cm}^{-3}$, and where the electrons are homogenous and isotropic, then Ginzburg and Syrovatskii (1964) have shown that the intensity of the radiation is given by

$$I_{\nu} = 1.35 \times 10^{-22} a(\gamma) LKH^{(\gamma+1)/2} \left(\frac{6.26 \times 10^{18}}{\nu} \right)^{(\gamma-1)/2} \quad (4)$$

$\text{ergs cm}^{-2} \text{s}^{-1} \text{ster}^{-1} \text{Hz}^{-1}$

in the presence of random magnetic fields. In this expression, a is a slowly varying function of γ with a value near 0.1 for the range of interest here, L is the length over which the electrons and magnetic fields are present, and H is the magnetic field strength. From equation (4), it is seen that, if the synchrotron spectrum is known, giving I as a function of ν over a reasonable frequency range, and L can be estimated, then K may be determined if H is known.

It is also important to know the relationship between the maximum in the synchrotron radiation and a given electron energy, which is

$$E_M = 4.7 \times 10^2 \left(\frac{\nu}{H_1}\right)^{1/2} \text{ eV} \quad (5)$$

If there is a spectrum of electrons of the type observed experimentally, rather than a monoenergetic distribution, then Webber has shown that the appropriate relationship is

$$E_{\text{eff}} = 2.5 \times 10^2 \left(\frac{\nu}{H_1}\right)^{1/2} \text{ eV} \quad (6)$$

The frequency range of interest in the LMC study here is from about 20 to 1400 MHz., corresponding then to electrons in the energy range from approximately 0.50 to 4.2 GeV for a 5 μ G field, or in fact a somewhat broader range when the distribution functions are considered, and 0.30 to 2.5 GeV for a 14 μ G field. The relevance of the magnetic field value range will be seen in the next paragraph.

It should be mentioned at this point, that historically there had been a concern regarding the synchrotron radiation observed in our galaxy. This was that the level appeared to be higher than would have been expected on the basis of the deduced electron spectrum and the magnetic field thought to exist. Recently, however, Fichtel, Ozel, and Stone (1990) have shown that with the interstellar cosmic ray electron spectrum now believed to exist based in part on the SAS-2 and COS-B gamma ray data at high latitudes, and the range of values for the total magnetic field including the random part now estimated from several sources, agreement can be obtained. These authors deduce a random magnetic field of about 11 μ G for the local region, consistent with the currently estimated range of 5 to 14 μ G, deduced in other ways.

V. THE LARGE MAGELLANIC CLOUD

Fichtel, Özel, and Stone further show that within the uncertainties of existing data the nonthermal radiation from the LMC and our galaxy have the same spectral shape. They then assume that the magnetic field pressure density in the LMC has the same relationship to the cosmic ray pressure as that in our galaxy as well as the relationship between the cosmic ray energy density and the electron spectrum being the same in the LMC as in our galaxy. Since the ratios of the cosmic ray electron intensity to the cosmic ray nucleon density and that to the magnetic field are assumed to be the same as in our galaxy, there is a fixed relation between K and H in Equation (4). Specifically, since the magnetic field pressure is proportional to H^2 , if K_0 and H_0 are the local values of K and H in our galaxy and $w(x_i)K_0$ is a value in a local region of the LMC, then the corresponding H value in the LMC is $[w(x_i)]^{1/2}H_0$, to maintain the relationship between the cosmic-ray and magnetic fields described earlier.

If L is known, $w(x_i)$ may be determined from the knowledge of the synchrotron radiation. Following Klein et al. (1989), Fichtel, Ozel, and Stone used an effective disc thickness for L of 1 kpc, the same as in our galaxy (Remember L for the LMC is the full thickness, not the half thickness as in our galaxy where the Sun is in the middle of the plane.). They then proceed to calculate w as a function of position for the LMC. They studied three frequencies 45 MHz, 408 MHz, and 1.4 GHz. There are different considerations at each

frequency and for each measurement including the degree of the thermal resolution, the beam size, and uncertainties.

For purposes of illustration, the results of their study at 1.4 GHz based on the measurements of Klein et al. (1989) are shown in Figure 2. It is seen that the cosmic ray density level on the average is similar to our own on the average although a bit lower if the assumptions stated at the beginning of this section are valid. Notice also that a nonuniform cosmic ray level is predicted.

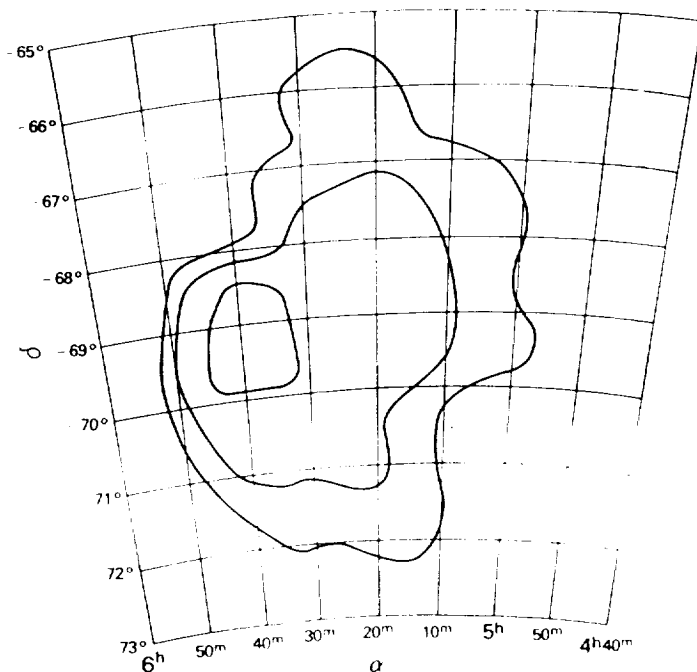


Fig. 2--The contour levels for the predicted cosmic ray energy density levels relative to those in our galaxy based on the 1400 MHz data of Haynes et al. (1986). The contour levels shown correspond to w equal to 0.59, 0.78, and 1.01. The contents of the figure are from Fichtel, Ozel, and Stone (1990).

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In Section III, it was noted that, if the cosmic rays are galactic and not universal and if other assumptions hold, then a prediction can be made for the cosmic ray density level. Before this step can be taken, however, the scale of coupling must be known. On the basis of the scale height perpendicular to the plane and other considerations it has been estimated that the scale height might be of the order of 1 kpc or somewhat greater. Consider the matter column densities shown in Figure 3 and remember that 1° corresponds approximately to 1 kiloparsec for the LMC. When corrected for the cosecant of the angle between the line of sight and the perpendicular to the plane of the LMC a level of 1.0×10^{21} atoms cm^{-2} is approximately equal to the local thickness of our galaxy. If one considers the coupling effect for the cosmic rays having a scale of 1 kpc or greater, one would predict the cosmic ray density profiles to be much flatter and not have nearly as sharp a peak. It is at least reasonable that such a process would lead to contours similar to those of Figure 2; however, it would appear that the magnitude would be somewhat different, perhaps by a factor of 1 1/2. This difference is within the known uncertainties. See Fichtel, Ozel, and Stone (1990) for a more detailed quantitative discussion.

As noted in Section II, future high energy gamma ray measurements should be able to provide information, which, although lacking the degree of angular

resolution that would be desired, will bear on this question and give a quantitative measure of the average cosmic ray density and hopefully some indication of their distribution. There are two benefits to the independent high energy gamma ray measurements in addition to their being a second

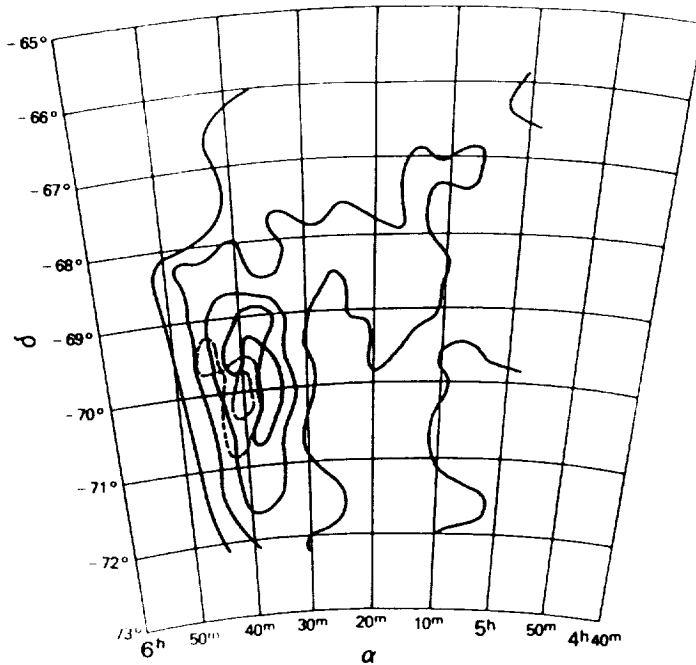


Fig. 3--The matter column density levels for the LMC. The solid contour lines refer to atomic hydrogen and correspond to column densities of (0.5, 1.0, 2.0, and 3.0) $\times 10^{21}$ atoms cm^{-2} . The dashed contour lines refer to molecular hydrogen and correspond to column densities of (0.5 and 1.0) $\times 10^{21}$ atoms cm^{-2} . For the atomic and molecular hydrogen column densities, the data of Mathewson and Ford (1984) and Cohen et al. (1988) respectively were used. The contents of the figure are from Fichtel, Ozel, and Stone (1990).

observation, one is that they are directly related to the dominant energy component of the cosmic rays, and the other is that their interpretation does not involve any assumptions about the magnetic fields.

VI. SUMMARY

The study of the matter density distribution and the synchrotron radiation in the case of the LMC suggest that the SMC and the LMC should be detectable in high energy gamma rays with EGRET and GAMMA, and M31 might be detectable. It also seems that for all three of these galaxies the cosmic ray density is expected to be of the order of that in our own galaxy, but varying slowly with position if the cosmic rays are galactic in nature. The study of the LMC synchrotron radiation indeed supports the nonuniformity of the cosmic ray density there.

A study of the synchrotron radiation and the matter column density in the LMC seems to indicate that it is possible to construct a consistent picture of the LMC based on the dynamic balance between the cosmic rays, the magnetic fields, and the kinetic motion of matter on the one side and gravitational attraction on the other and the additional feature that the magnetic field must be strong enough to contain the cosmic rays. Further a comparison of the contours related to the matter density and those related to the cosmic ray density predicted by the synchrotron radiation suggests that the scale of the coupling between the cosmic rays and the matter is probably of the order of a kiloparsec or larger since there is a smoothing required relative to the matter density contours to make the cosmic ray contours more consistent with

those of the synchrotron radiation. This scale of coupling is quite reasonable based on considerations of our own galaxy.

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DISCUSSION

Stan Hunter:

When you use the magnetic field and cosmic ray abundance observed in our galaxy to predict the gamma-ray flux from the LMC, how do you account for spiral vs. irregular structural difference?

Carl Fichtel:

It is only assumed that the cosmic ray energy density and the magnetic field energy density have the same ratio. This implies that the cosmic ray sources are adequate. The latter seems justified on the basis of the relative level of the two. There seems no reason to suspect a difference between the two galaxies, particularly, since the irregular field appears to significantly exceed the uniform component in our galaxy.

Active Galaxies

